EXPERIMENTAL STUDY OF A PASSIVE THERMAL CONTROL SYSTEM FOR SPACE SUITS

STATUS REPORT NO. 9

NASA R-135

17 January 1967 - 17 July 1967

24 July 1967

Prepared
by
Advanced Projects Division
Clothing & Organic Materials Laboratory
U. S. Army Natick Laboratories
Natick, Massachusetts

SUBMITTED BY:

Ferdinand Votta Jr.
FERDINAND VOTTA, JR.
Research Chemical Engineer

APPROVED BY:

Leo A. Spano
LEO A. SPANO, CHIEF
Advanced Projects Div.

CONTENTS

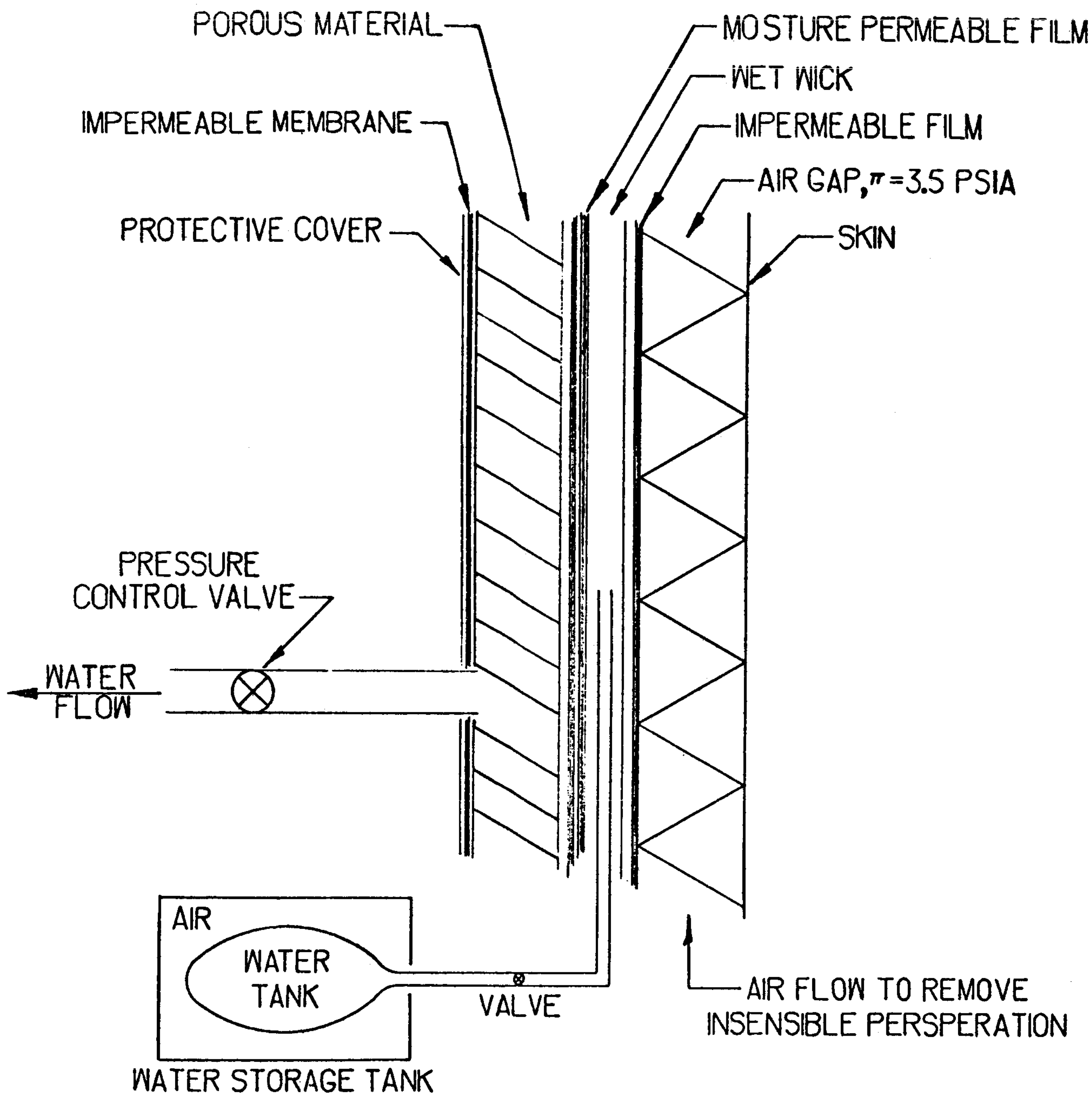
1. Introduction

Two passive thermal control systems for space suit use in an extra-vehicular environment have been proposed by the Advanced Projects Division, U. S. Army Natick Laboratories in their 12 August 1965 report entitled, "Preliminary Study of Two Passive Control Systems."

The first proposed system (System A) is a completely passive system requiring a selective moisture permeable membrane to provide the necessary cooling effect. Successful operation of this system depends upon the development of a membrane having a high permeability to water vapor and at the same time being impermeable to oxygen. No membrane with the proper characteristics is currently available although work on the development of such a membrane is currently in progress at the U. S. Army Natick Laboratories.

The second proposed system (System B) requires an impermeable membrane and a permeable membrane which need not be selective. As indicated in the Advanced Projects report, System B could be engineered relatively soon with our current state of technical knowledge and current technology of material.

The essential components of System B are shown in Figure 1 and would include the following: The skin would be separated from an impermeable membrane by a narrow air gap controlled by a spacing material. The air gap would keep the skin dry and contain the life support gas at the required pressure. The impermeable membrane would keep the life support gas from



HEAT REGULATION BY EVAPORATION COOLING
FIGURE 1 SYSTEM B

escaping into space. The impermeable membrane would be covered and in contact with a wet wick which would itself be covered by a permeable membrane. The permeable membrane would be separated from an outer impermeable membrane by a porous vapor space. The vapor space would vent to space through a pressure control valve. The cooling would thus be obtained by the controlled diffusion of water vapor through the permeable membrane and vaporization of the water into the vapor space.

The purpose of this investigation was to experimentally test the design concept of System B under simulated space conditions and to study its operating characteristics using various materials of constructions.

2. Experimental Equipment

A schematic diagram of the equipment used in this investigation is shown in Figure 2. Photographs of the equipment are shown in Figures 3, 4 and 5. The equipment consists of a test chamber, two vacuum pumps, two vapor traps, a motor operated control valve, vacuum or pressure measuring instruments, temperature control and measuring instruments, and various small valves and piping.

The test chamber consists of an annular space formed by two concentric brass pipes. Each pipe was sealed off at one end by being welded to a disc or head and each was welded to a flange at the other end. The flanges were bolted together with a gasket between them to form the test chamber. The outer pipe is a standard 16 inch pipe and the inner pipe is a standard

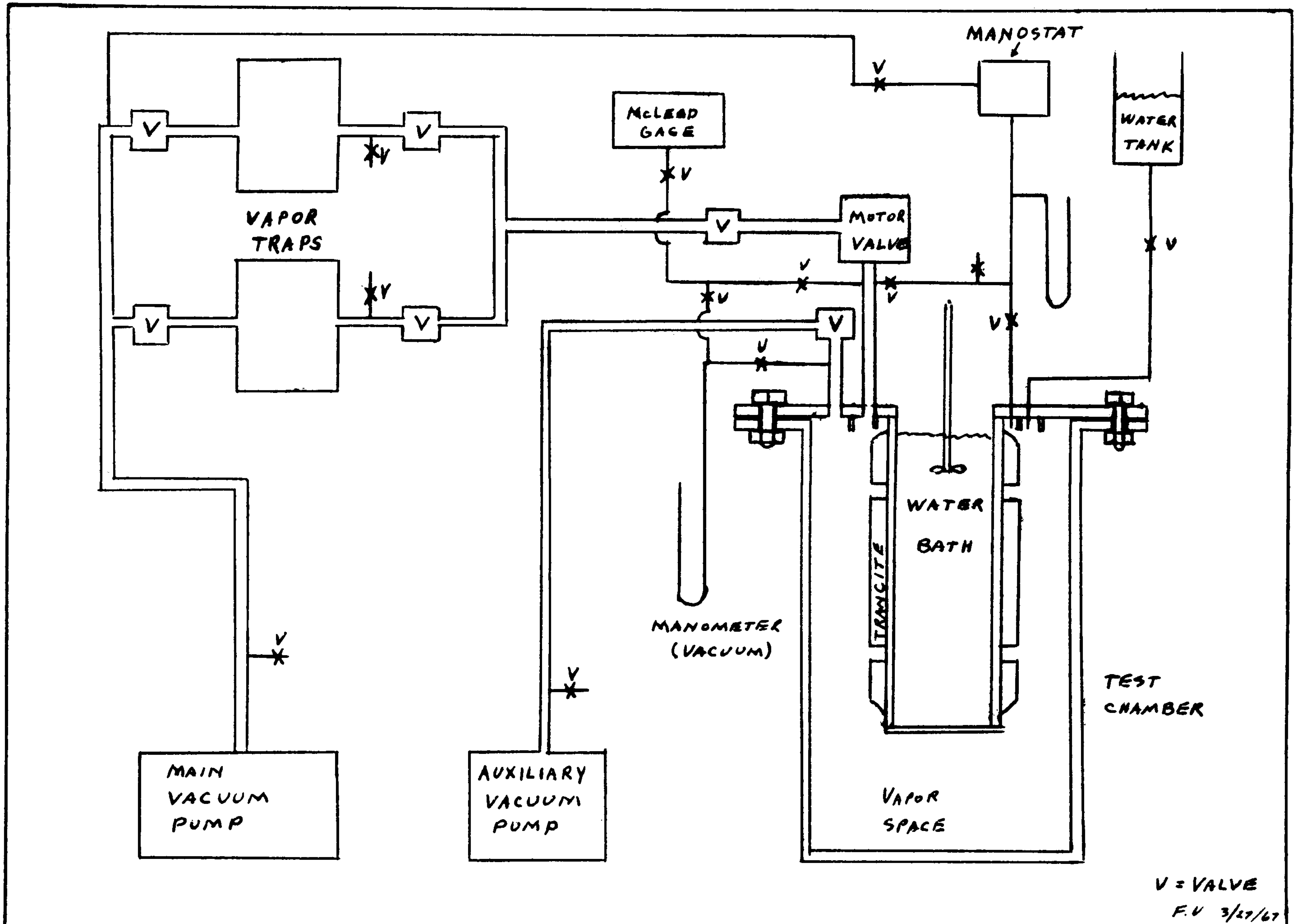


Figure 2

Schematic Diagram of Apparatus

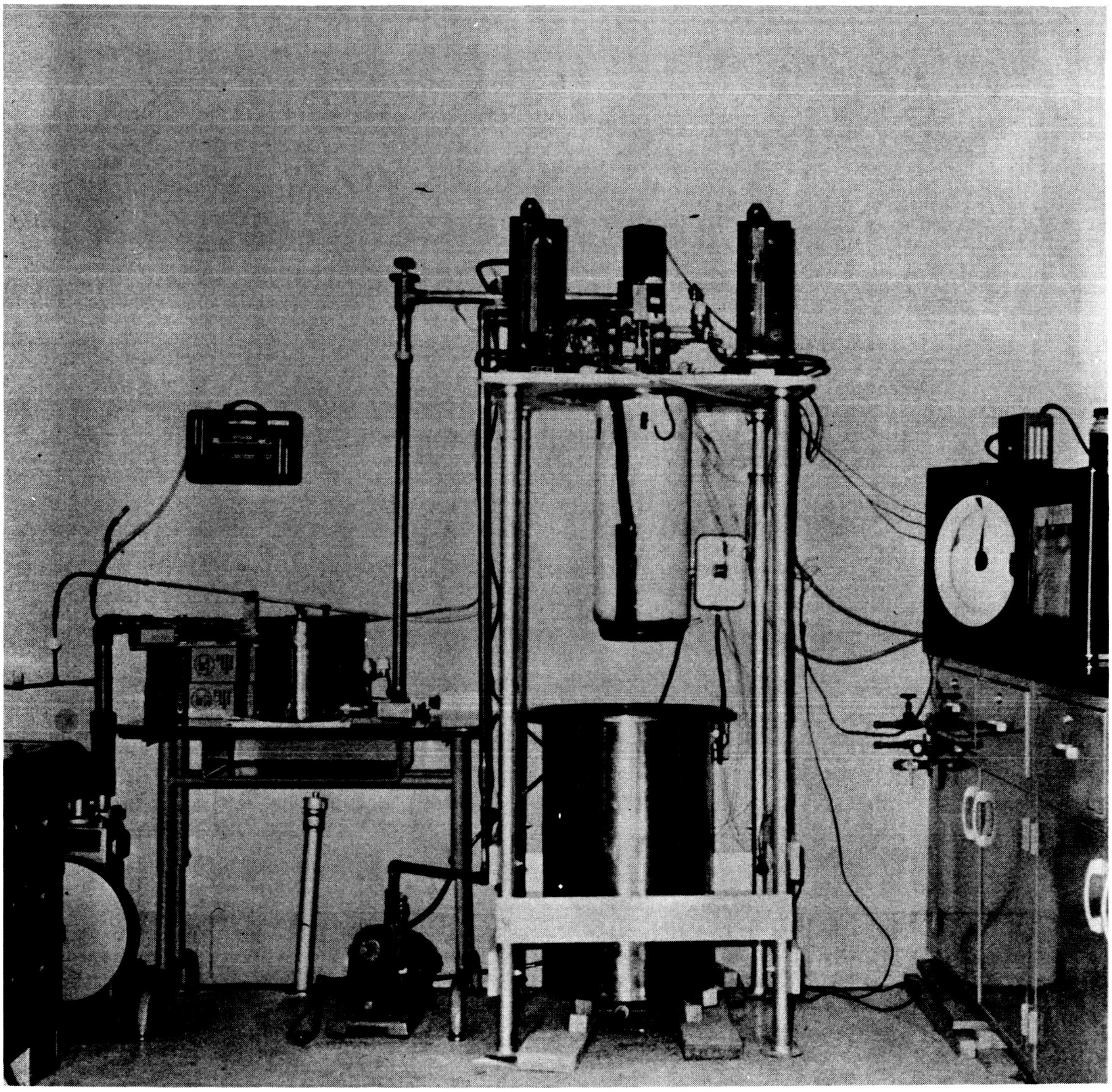


Figure 3

Complete apparatus with outer pipe removed

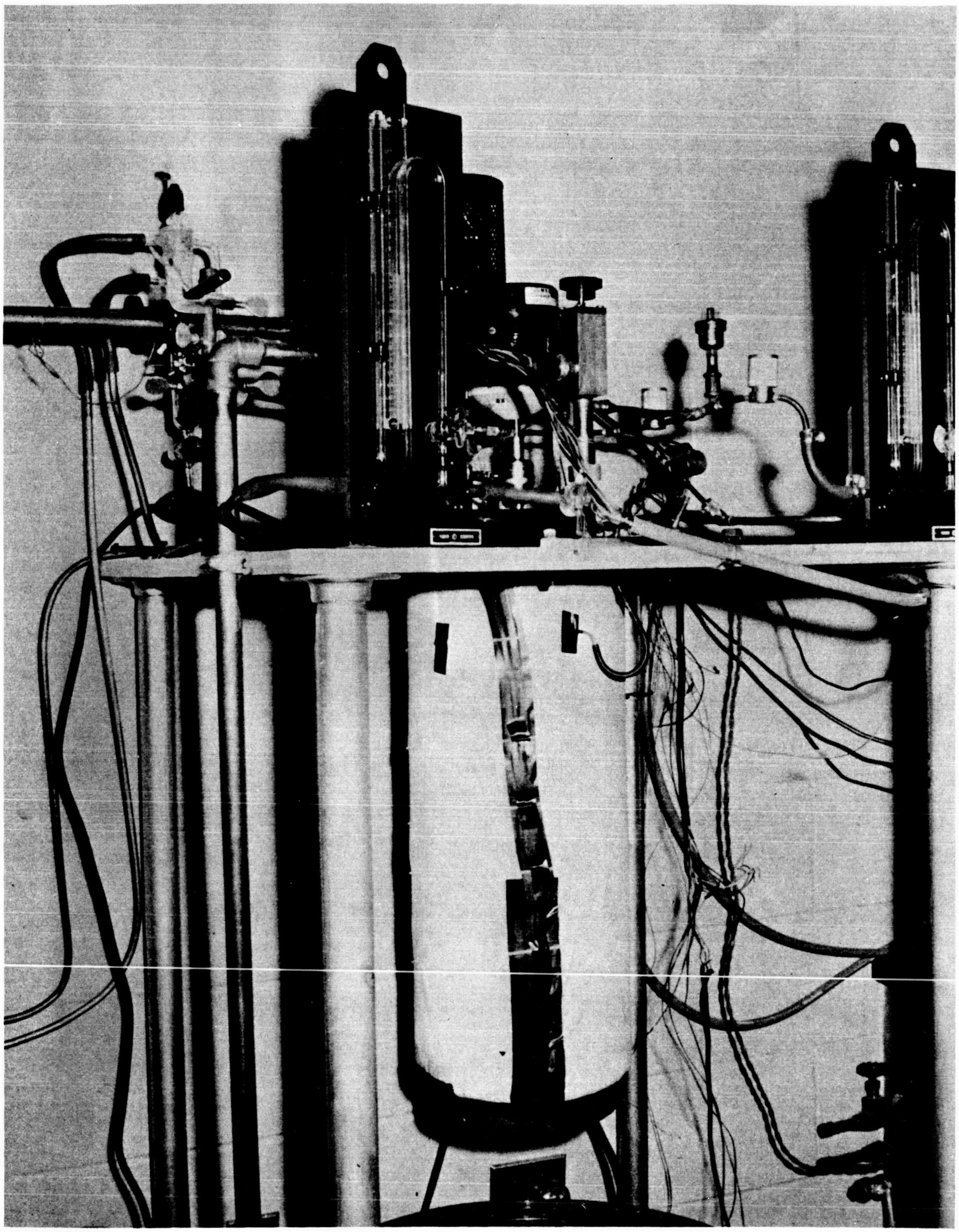


Figure 4

Inner pipe and measuring devices

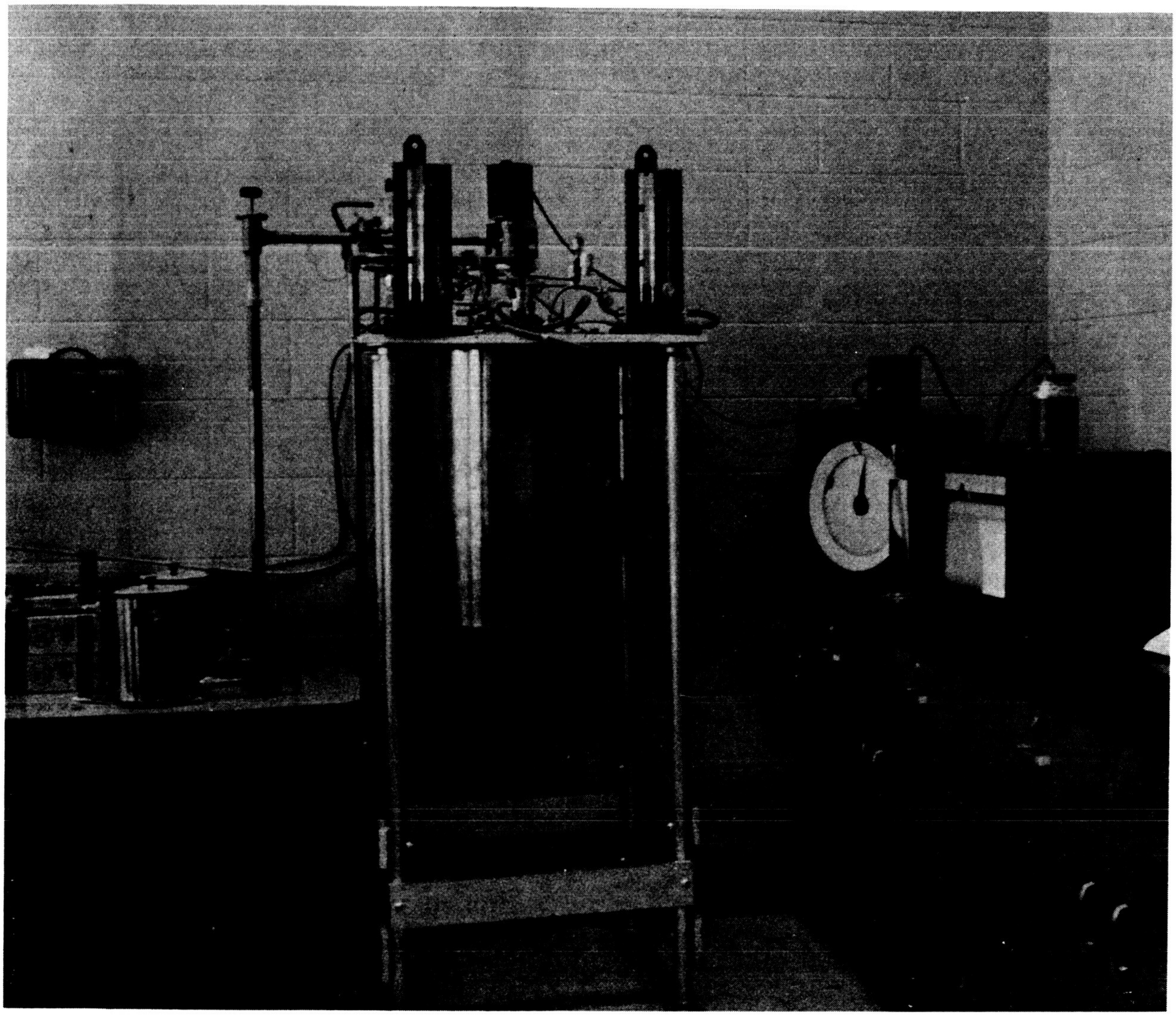


Figure 5

Assembled System

8 inch pipe. An asbestos cement or transite pipe, was mounted over the inner pipe and served as the simulated skin surface. The temperature drop through the transite pipe was used as the basis for calculating the rate of heat input to the system. The asbestos cement pipe was divided into three sections to reduce longitudinal heat transfer. The center section served as the test section. Eleven thermocouples were installed to the surfaces. Each thermocouple consists of three junctions connected in parallel. Heat was supplied by an electrically heated hot water bath inside the inner pipe. The water temperature was controlled by a mercury in glass thermoregulator.

The motor operated valve in the vacuum line from the vapor space controlled the pressure in that space and thus controlled the rate of water vaporization from the wet wick. It was operated by a potentiometric thermoregulator. In an actual space suit the pressure control valve would be activated by the skin temperature, but for these tests it was found that more uniform operations resulted when the valve was activated by one of the wick thermocouples.

Two other potentiometers were used to measure temperatures. One, a 24 point Honeywell - temperature recorder, was used to record the E.M.F. from all the thermocouple junctions in the system. The other potentiometer was a two pen Moseley - strip chart recorder. Generally, one pen was used to measure the temperature of the outer surface of the transite (simulated skin temperature) and the other to measure the temperature drop through the asbestos cement from which the rate of heat flow was calculated. However, by using a thermocouple selector switch, it was possible to use the strip chart recorder to measure and record other key temperatures.

The simulated suits were mounted over the transite skin simulator. The impermeable membrane was cemented and clamped to the projections on the flange and to the lower portion of the inner pipe. Figures 3 and 4 show the equipment with the outer pipe dismantled and the impermeable membrane in place. Figure 5 shows the equipment assembled with the outer pipe bolted in place.

3. Description of Clothing Systems Tested

To date two clothing systems or units have been constructed and tested -

Suit No. 1 consisted of a polyethylene-saran spacing material mounted over the transite skin simulator so as to form an air gap. The polyethylene-saran spacer was 0.285 inches thick and weighed 33 oz. per sq. yd. A white rubberized fabric was mounted on the outside of the spacer and attached by cement to the top flange and to the lower portions of the inner brass pipe. The joints on the rubberized fabric were made leak tight and it thus became an impermeable membrane separating the air gap from the remainder of the system. The water distribution was obtained by 12 feet of 1/16 inch teflon tubing coiled outside the rubberized fabric. The teflon tubing was punched by a needle about every two inches. The wick consisted of a single layer of absorbent paper toweling covered by woven nylon. The wick was covered by a tightly fitting layer of leather. The entire system was then wound tightly with nylon tape so that it would withstand the pressure differential between the air gap and the outside.

Suit No. 2 was similar to Suit No. 1 except that a layer of cotton shirting was placed next to the skin simulator. The polyethylene-saran spacer which was in contact with this shirting was only 0.10 inch thick. Also the wick was formed by six layers of cotton shirting covered by the layer of woven nylon.

4. Operating Procedure

Before conducting any experimental tests the system was leak tested, both between the entire system and the atmosphere, and between the air gap and vapor space.

In carrying out a test the following procedure was followed: The water bath heater and stirrer were turned on and the bath heated to the desired temperature. The vapor space and air gap were slowly evacuated with a bypass valve between the two open so that the pressures would be equalized. When the pressure reached 180 mm of Hg (3.5 psi) the bypass valve was closed and full vacuum was applied to the vapor space. Originally, a manostat was planned for pressure control of the air gap. However, the glass manostat broke and it was found that manual control of the pressure was not difficult as the air gap pressure changed very slowly. Ice was put into one of the vapor traps. The main vacuum pump was a ballast pump which could handle up to 25 mm Hg partial pressure of vapor but the pumping speed was increased if some of the vapor was condensed and separated before the pump. In three of the runs where very high pumping speeds were required, dry ice and acetone were used in the traps. The controller operating the automatic control valve was set at the estimated required wick temperature and water was allowed to flow into the wick. Sufficient water was added so that the six wick thermocouples were nearly the same. The water vaporized from the wick and cooled it very rapidly. The simulated surface temperature also cooled rapidly. When the wick temperature reached its set point the motor valve closed and vaporization stopped. The temperatures then started to rise until the control valve reopened. The temperature set point for the valve was adjusted until the simulated skin temperature was maintained at the desired value. After conditions in the system had been constant for approximately 30 minutes, the temperatures were recorded and the run ended.

5. Results

The results were summarized in Figures 6 and 7. These show the calculated and experimentally measured heat flow rates for each of the clothing system tested as a function of wick temperature. Figure 6 is for a simulated skin temperature of 91°F. and Figure 7 is for a temperature of 96°F. The

Figure 6

Heat Flow Rate

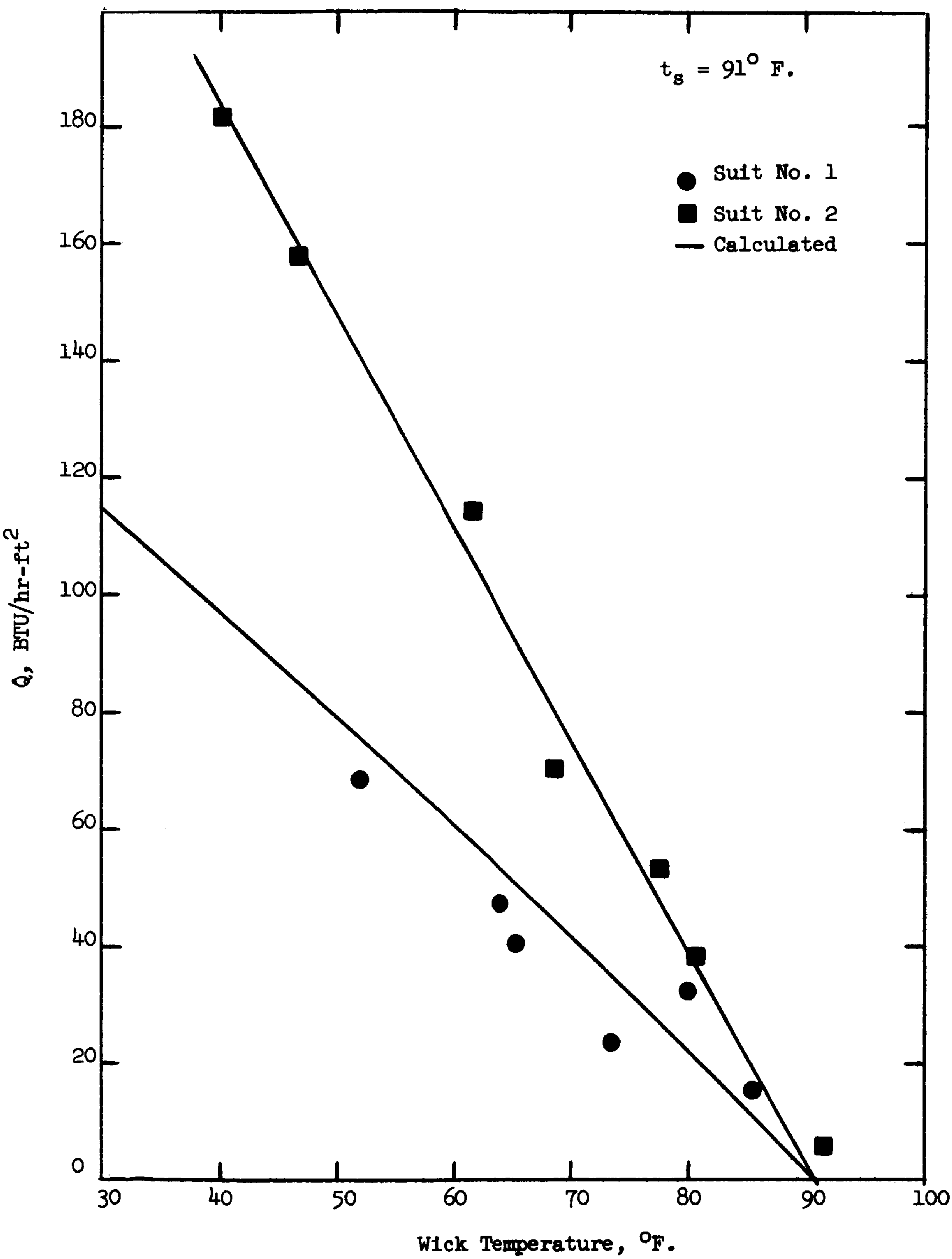
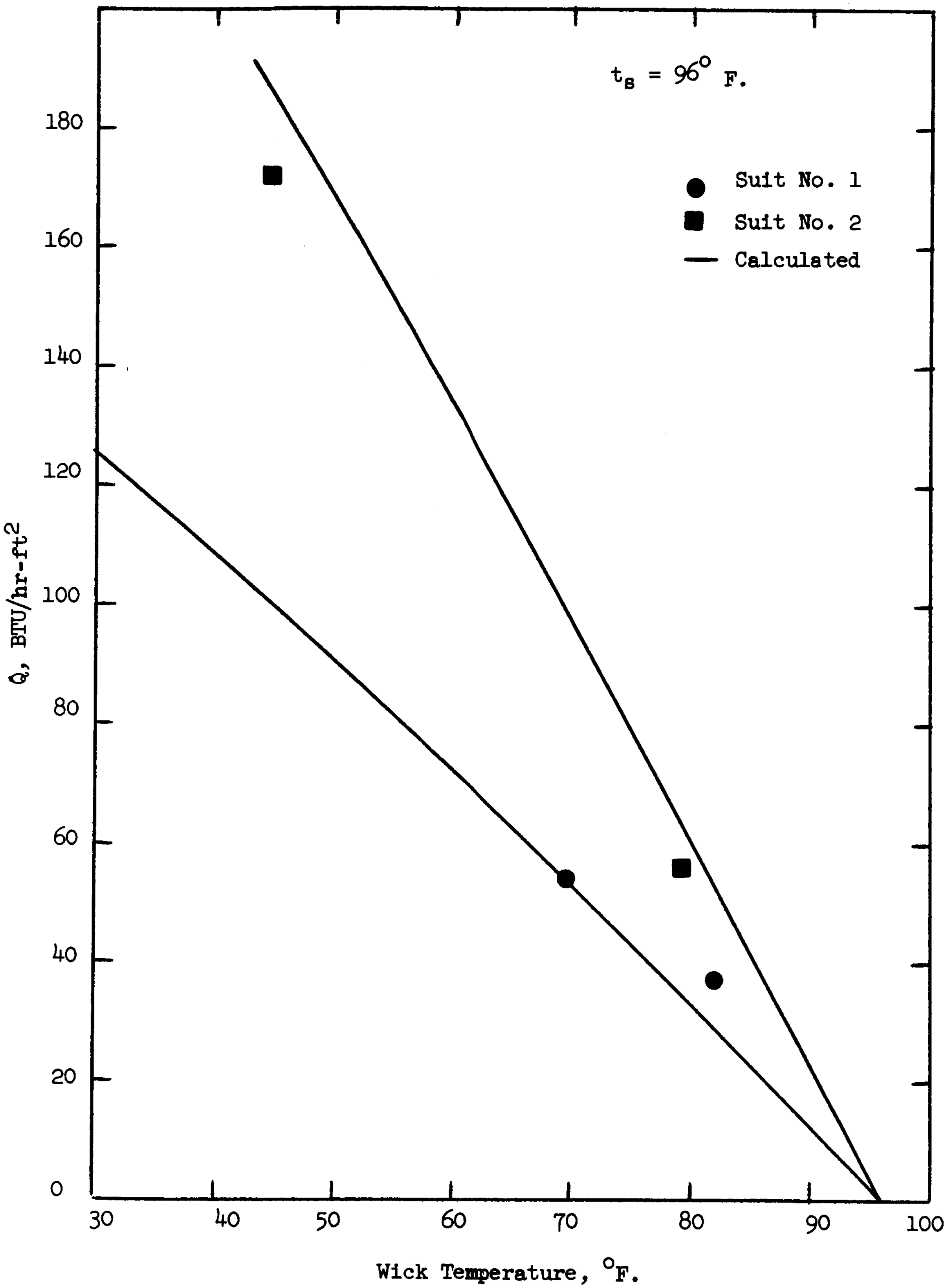


Figure 7

Heat Flow Rate



calculated heat flow rates were determined for combined conduction and radiation across the air gap. In the radiation calculation, an emissivity of 0.96 was assumed. Values of the thermal conductivity of the air gap spacing material used in the conduction calculations were determined and supplied at the U. S. Army Natick Laboratories.

The agreement between the calculated and measured cooling rates is very good. Also, with a simulated skin temperature of 91°F. it was possible to obtain a cooling rate of 182 Btu/(Hr x sq. ft.). For a suit with a total area of 20 sq. ft. this would be equivalent to a cooling rate of 3640 Btu/hr., which is considerably in excess of the goal of 3000 Btu/hr.

While not measured quantitatively, a significant difference in the speed of response and operating characteristics of the two suits were noted. Suit 2 required considerably more water to wet the wick uniformly and responded to temperature changes more slowly than did Suit 1. These differences, it is believed, are due to the difference in the wick construction of the two suits. The multilayer cotton wick of Suit 2 required considerably more water and the cotton fibers apparently did not release the water as readily as the thin wick in Suit 2.

6. Conclusions and Recommendations

It is possible with our current state of technical knowledge to design a passive thermal system which will remove heat from a man in a space suit at rates in excess of 3000 Btu/hr without depending upon sweating. The man can be maintained in a relatively dry environment.

Additional experimental work should be carried out in which various wick designs could be studied. It would seem that the desired characteristics should include rapid response to temperature changes and the requirement of a relatively small amount of water for complete wetting. These characteristics will probably be met by synthetic materials since they would not tie up relatively large quantities of water in the fiber.